Transmitting SPIHT Compressed ECG Data over a Next-Generation Mobile Telecardiology Testbed

[1]Chia-Yuan Huang, [2]Shaou-Gang Miaou

[1,2]Communication Technology Research Laboratory
Dept. of Electronic Engineering, Chung Yuan Christian University, Chung-Li, Taiwan

Email: [1]huang@wavelet.el.cycu.edu.tw [2]miaou@ wavelet.el.cycu.edu.tw

Abstract- **Recently, the set partitioning in hierarchical tree (SPIHT) was shown to be an excellent algorithm for ECG compression. However, how it performs in a cellular phone based wireless environment for telemedicine applications is not known. In this paper, a joint design for SPIHT-based ECG data compression method over a next-generation mobile telecardiology testbed based on the 3G cellular phone standard is proposed and the performance of the testbed for the compressed ECG data segments selected from the MIT-BIH arrhythmia database is evaluated in terms of BER (bit error rate), PRD (percent of root-mean-square difference), compression ratio (CR), transmission time, and diagnostic quality. The simulation results show that during the successful transmission of compressed ECG (when BER is less than 10^{-5}), a CR of 8:1 provides a 87.5% reduction in total transmission time and a higher CR up to 20 can reduce up to 95% of the required time to transmit the ECG. Furthermore, most characteristics of the received ECG waveform, such as P wave, QRS complex, and T wave, can be reserved with clinically acceptable quality.**

Keywords **- 3G wireless communications, mobile telecardiology, ECG compression, SPIHT, wavelets**

I. INTRODUCTION

Wireless and mobile telemedicine systems provide a new way for health care delivery. Due to the ubiquity and low cost of the cellular phone, the current second generation (2G) digital cellular network can play an important role in telemedicine applications, where high mobility and low cost are essential [1]. The 2G traffic and the number of users are still increasing. However, data rates are limited - a single channel data rate with a GSM telephone is 9.6 kbits/s. Therefore, the cellular network will gradually evolve from 2G to the third generation (3G). The 3G system can provide mobile users with a high-speed Internet access, video and many other communications services, including a mobile medical service. The International Telecommunication Union Radio Communication Standardization (ITU) has developed a concept known as IMT-2000 (International Mobile Telecommunications – 2000) for 3G systems and called for proposals in radio transmission technology by June 1998. Among all proposals for IMT-2000, wideband-code division multiple access (W-CDMA) is the most promising candidate for 3G wireless access due to its numerous advantages and its state as being standardized in the 3rd Generation Partnership Project (3GPP)[2-5].

Recently, the mobile telemedicine system design based on GSM was addressed in [6-7]. A telecadiology service based on the 3G standard was also investigated in [8]. In all these papers ECG signals are transmitted directly without compression. However, data compression is essential to overcome bandwidth limitations of cellular telephonic channels for real-time transmission. This factor is considered in the recent development of mobile telemedicine systems [9-10].

The wavelet transform techniques for ECG data compression have received a great deal of attention [11-15]. Recently, an excellent wavelet-based coding technique called the set partitioning in hierarchical tree (SPIHT) for ECG compression was proposed [14-15]. One interesting property of the SPIHT is its progressive coding capability, where signal quality can be improved gradually as the compressed bit rate increases. The encoded bit stream can be stopped as soon as the desired quality is met. However, no study to date has addressed the integration issues of the SPIHT-based ECG compression techniques with the design and functionality issues of the 3G-based mobile telecardiology system. These issues will be the main theme of this paper.

The rest of the paper is organized as follows. In Section II, we briefly summarize SPIHT compression algorithm for ECG data and address the design and modeling issues of integrating the SPIHT algorithm with the 3G-based telecardiology testbed. Section III presents the simulation results for the testbed, where selected ECG data from the MIT/BIH arrhythmia database are transmitted. Finally, a conclusion is given in Section IV.

II. NEXT-GENERATION MOBILE TELECARDIOLOGY TESTBED

A. SPIHT Compression for ECG Data

Generally, most of the energy in an ECG signal is concentrated in the low-frequency region and the amplitude spectrum of the signal decays with increasing frequency. The variance decreases as we move from the highest to the lowest levels of the subband pyramid. Furthermore, it has been observed that there is temporal self-similarity among subbands. The temporal orientation tree defines temporal relationship on the hierarchical pyramid in such a way that each node has either no offspring or two offspring. All these properties would manifest themselves in the discrete wavelet transform (DWT) of the signal.

DWT results in wavelet coefficients to be encoded by the SPIHT strategy. The detail of SPIHT coding can be found in many literatures, say [14] and [15]. Only a short summary is

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Abstract

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provided here. The SPIHT algorithm utilizes three basic concepts. First, it arranges wavelet coefficients in temporal-orientation trees. Second, it partitions the coefficients in tree structure into sets defined by the level of the highest significant bit in a bit-plane representation of their magnitudes. Third, encode and transmit the bits associated with the highest remaining bit planes first.

SPIHT consists of two main stages, sorting and refinement. In the sorting pass, SPIHT sets a magnitude threshold 2^m, where m is called the level of significance. The subset of coefficients c_i in the subband $\Im$ is said to be significant if $\max_{i\in\Im}\{|c_i|\} \geq 2^m$; otherwise, it is said to be insignificant. If the subset is significant then it is split further according to the temporal orientation tree until all the significant sets have a single significant element. The algorithm tests the significance of the elements in each subset and moves coordinates of corresponding coefficients to one of three lists: 1) the list of significant coefficients (LSC); 2) the list of insignificant coefficients; 3) the list of insignificant sets. Following each sorting pass, except the first one, is the refinement pass. In the refinement pass, send to the decoder the mth most significant bit of the coefficients in LSC, which is obtained at a higher threshold. After the refinement pass, decrease m by one, and continue the process until some bit budget or a desired quality level is reached. Following the simple concept of embedded scalar quantizer, the decoding process is straightforward once the encoded bits for wavelet coefficients are obtained.

B. *3G-based Mobile Telecardiology Testbed*

A 3G-based mobile telecardiology testbed with a SPIHT coder are shown in Fig. 1. The detailed description of the system blocks and the associated sub-blocks with relevant simulation and modeling details are described elsewhere [3-5][8][17]. However, a brief description of the main design modules is given here for completeness. The key functions performed in the transmitting path in a 3G signal processing structure are the signal and channel coding, inter-leaving, rate matching and modulation. The receiver blocks are essentially the reverse of the transmitter blocks. Since this testbed is based on 3GPP FDD (Frequency Division Duplex) mode standard, its data traffic channel has five service rates, 12.2, 64, 144, 384, and 2048 kbps, to be selected [5][17]. For the design described later, we choose 12.2kbps as the data traffic of 3G-based testbed channel because this should provide enough bandwidth for clinical ECG real-time telemedical transmission. The basic 3G-based telecardiology testbed is comprised of the following generic cellular blocks: (1) 3G-based data encoder; (2) 3G-based transmitter; (3) 3G-based cellular channel model; (4) 3G-based receiver; and (5) 3G-based data decoder. A brief description for each modular block is given next.

3G Data Encoder: This block consists of several subblocks, including channel encoder, rate matching, and interleaving. After the ECG signal source is compressed by the SPIHT, the resultant bits are encoded frame-by-frame and the frame length is 10ms. First, it is attached by CRC (Cyclic Redundancy Check) code for error check at the receiving end. For channel coding, note that 3GPP systems typically use a 1/2 or 1/3 rate convolution encoder for low rate data, such as speech processing, and a 1/3 Turbo encoder for high rate data. Here 1/3 rate convolution encoder is selected for the SPIHT ECG data because the lower data rate of the 3G channel bandwidth (12.2 kbps) is used. Next, the inter-fame interleaving is performed and the rate matching is used to match the number of bits to be transmitted to the number of bits allowed on a single frame. The 2nd interleaving performs intra-frame interleaving and the data field is formatted with various overhead fields to create a wideband code-division multiple access (W-CDMA) frame required for the 3GPP FDD mode structure.

3G Transmitter: This part includes spreading, scrambling, and modulation. The spreading modulation scheme is the dual channel QPSK. Each mobile unit has a dedicated physical data channel (DPDCH) to deliver the traffic data and a dedicated physical control channel (DPCCH) to deliver the control data. Two channels are I/Q multiplexed. For data spreading, OVSF (Orthogonal Variable Spreading Factor) and long or short random scrambling code are used for channelization and scrambling, respectively. The modulated output is a complex envelope signal.

3G Cellular Channel Model: For the complex baseband simulation, besides basic additive white Gaussian noise (AWGN) channel, three optional channel models can be selected to simulate the desired realistic cellular channel conditions such as in urban, rural, outdoor to indoor and pedestrian, or indoor office environments. These models provide several useful static channels derived from the 3GPP standards. For example, the Rayleigh fading channel provides various parameters such as the mobile user velocity and produces a fading channel with complex output for a complex input signal. The moving channel sets up a two path channel, with the first path fixed and the second path moving in a sinusoidal fashion. The birth-death channel provides a two path channel where a channel path "dies" and reappears immediately with a new delay [17].

3G Receiver: This modeling block is used to despread, descramble and demodulate a 3G signal. For the multipath propagation caused by natural obstacles such as buildings, hills, and so on, it is necessary to use a Rake receiver in order to recover or collect the energy of all paths. Basically, a Rake receiver is a collection of multiple correlation receivers. According to the required system performance, standard 3G design procedures, and compatibility with the medical data specifications, smart adaptive antennas and multiuser detection are options in the 3G standard.

3G Data Decoder: This block decodes the various fields of channel traffic. Each W-CDMA frame is decoded. The data field of each frame is deinterleaved and the resulting main data field is then rate recovered. The rate recovered data field is deinterleaved again and then decoded using a convolution

decoder with the Viterbi algorithm. Next, it is decoded to check frame errors and remove CRC attachment by the CRC decoder. The resultant bits from the decoder are fed to the SPIHT decoder to retrieve the decompressed ECG data.

As shown in Fig. 1, the 3G-based mobile telecardiology testbed and related models are simulated using SystemView by ELANIX® software and the associated Entegra's 3G design libraries on a PC-based Pentium III computing environment [16-17]. The SPIHT method was implanted in MATLAB and the associated Wavelet and Signal Processing Toolboxes [18].

III. SMULATION RESULTS AND DISCUSSION

In this section, we present the performance results of the mobile telecardioloy testbed. For the test ECG data in our experiment, Record 117 from the MIT-BIH arrhythmia database is used. All data are sampled at 360 Hz with 11 bits/sample precision. For the SPIHT implementation, the frame size and number of levels of the wavelet transform are chosen to be 1024 samples and six levels, respectively. A typical SPIHT compressed ECG signal (2.5-min long) with compression ratio (CR) of 8 : 1 and PRD of 1.05% is fed to the transmitter or mobile unit of our mobile telecardiology testbed and the performance of the testbed is evaluated at the receiving end of the testbed by the PRD results under different channel distortion conditions where only AWGN is considered. The signal-to-noise ratio (SNR) is used to quantify different distortion conditions. Given the SNR of 4, 6, 8, and 10 dB, the corresponding BER (bit error rate) performance and PRD values are shown in Table I. From Table I, we found that as SNR increases, BER and PRD decrease substantially.

In Fig. 2, typical waveforms of the original and the reconstructed ECG signals at the receiver for 4, 6, and 8 dB SNR levels are shown. When SNR = 4dB, the ECG signal transmission essentially fails since PRD is too high and most portion of the reconstructed signal in Fig. 2 (b) is beyond recognition. When SNR = 6 dB, although the major part of ECG signal frames is reconstructed normally, a few frames, such as the second frame in Fig. 2 (c), are still damaged and the reconstructed signal can not achieve acceptable clinical or diagnostic quality. At SNR = 8 dB, the BER is less than 10^{-5} and most characteristics of the received ECG waveform in Fig. 2 (d), such as P wave, QRS complex, and T wave, can be reserved with good quality. The results for SNR = 10 dB are similar to the 8-dB case. Therefore, under BER of 10^{-5}, the mobile telecardiology testbed can successfully transmit the SPIHT compressed ECG data under consideration. The amount of data sent depends on the compression ratio, which, in turn, depends on the signal quality required by the medical specialist. Due to the excellent coding performance of SPIHT, a higher CR up to 20 : 1 still achieves acceptable reconstruction quality over our testbed.

Consider the transmission of a 30-min long ECG. It requires 584 s (360 samples/s ×11 b/sample × 1800 s) / (12200 b) with no compression. The required transmission time for compressed signal with different compression ratios is listed in Table II. The high coding efficiency of SPIHT enables much more efficient use of the connection made and even reduce up to 95% of the required time to transmit the ECG signal over the testbed.

IV. CONCLUSION

In this paper, a new integration design for SPIHT-based ECG data compression method over a next-generation mobile telecardiology testbed based on 3G cellular phone standard is proposed and the performance results of the testbed using the compressed ECG data are also presented. The performance is evaluated in terms of BER, PRD, and visual clinical inspection. The simulation results show that during the successful transmission of SPIHT compressed ECG under BER of less than 10^{-5}, a CR of 8:1 provides a 87.5% reduction in total mobile transmission time and a higher CR of 20 can even reduce up to 95% of the required time to transmit the ECG. In these cases, most characteristics of the received ECG waveform, such as P wave, QRS complex, and T wave, can be reserved with clinically acceptable quality.

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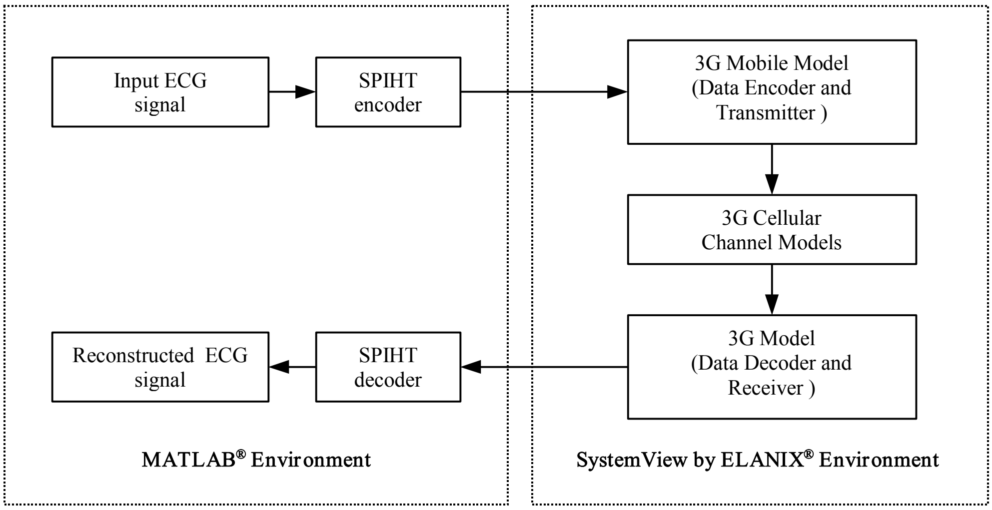

Fig. 1. The joint design and modeling platforms of SPIHT compression and the 3G-based mobile telecardiology testbed

TABLE I

BER PERFORMANCE AND PRD VALUES FOR VARIOUS SNR LEVELS.

SNR (dB)	4	6	8	10
BER	6.51×10^{-2}	8.82×10^{-4}	$<10^{-5}$	$<10^{-5}$
PRD (%)	488.23	10.3	1.05	1.05

TABLE II

THE REQUIRED TRANSMISSION TIME AND ITS REDUCTION PERCENTAGE RELATIVE TO NO COMPRESSION FOR THE COMPRESSED SIGNAL WITH VARIOUS COMPRESSION RATIOS.

CR	4	8	16	20
PRD (%)	0.58	1.02	1.93	2.41
Required time to transmit ECG with SPIHT compression (584 sec if no compression)	146 sec	73 sec	37 sec	29 sec
Reduction Time (%)	75	87.5	93.75	95

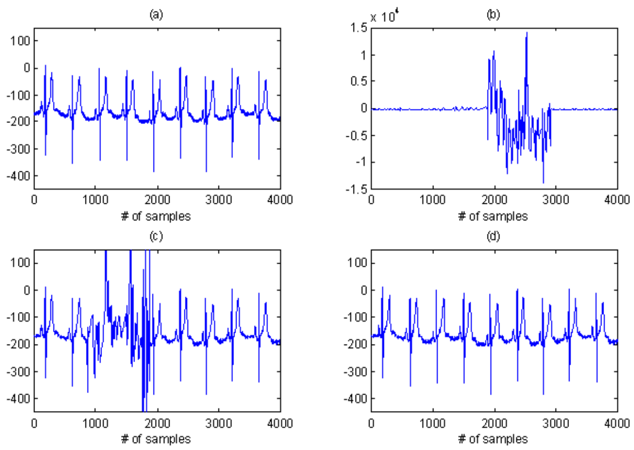

Fig. 2. Typical ECG waveforms obtained in the testbed. (a) an original signals; the reconstructed ECG signals of (a) at the receiving end given (b) 4; (c) 6; and (d) 8 dB SNR level.